Retreating Glaciers of the Himalayas: A Case Study of Gangotri Glacier Using 1990-2009 Satellite Images

Jennifer Ding

Texas Academy of Mathematics and Science (TAMS)

Mentor: Dr. Pinliang Dong
Department of Geography, UNT

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Introduction (1)

- What is a glacier?
  - A glacier is made up of fallen snow that compresses into large, thickened ice masse over many years.

Introduction (2)

- What is a moraine?
  - A moraine is any glacially formed accumulation of unconsolidated glacial debris (soil and rock).

Introduction (3)

- Why study glaciers?

Three major reasons:

(1) Effects of glaciers on land surface temperature, and air/soil moisture;

(2) Glaciers as freshwater resources;

(3) Glaciers as sensitive indicators of global climate change.

Introduction (4)

- Why choose the Himalayas?

(1) The third pole of the planet Earth;

(2) The first pole of the planet Earth in terms of direct impact to human population – several major river systems originate from the Himalayas, affecting over three billion people;

(3) A unique environment for studying global climate change due to the low level of human activity.

Introduction (5)

- Why use satellite images?

(1) Spatial coverage:
A big picture of the study area, and sub-meter level spatial resolution.

(2) Temporal coverage:
Over 30 years records.

(3) Data analysis:
Efficient digital image analysis using computers.

Literature Review

- Racoviteanu *et al*. 2008: Mapping Himalayan glaciers using remote sensing.
- Yao *et al*. 2007: Glacier retreat on the Tibetan Plateau.
- Gupta et al. 2007: Mapping dry/wet snow cover in the Indian Himalayas.
- Hall *et al*. 1995: Mapping global snow cover using remote sensing.
- … …

Limitations of Relevant Studies

- Limited datasets covering a single year or limited timeframe;
- High resolution images were not available for detailed image interpretation;
- Inaccurate glacier retreating rates resulted from the above limitations.

Research Objectives

(1) Detect moraine-covered glacier using medium -resolution Landsat Thematic Mapper (TM) and high-resolution IKONOS images.

(2) Quantify changes of moraine-covered Gangotri Glacier from 1990 to 2009, and provide insight into heated discussions on glacier retreating rates in the area.

Study Area: Gangotri Glacier

- One of the largest glaciers (25 km x 30 km) in the Himalayas
- One of the major sources for the River Ganges on the Indian Sub-continent;
- About 400 million people live close to the River Ganges.

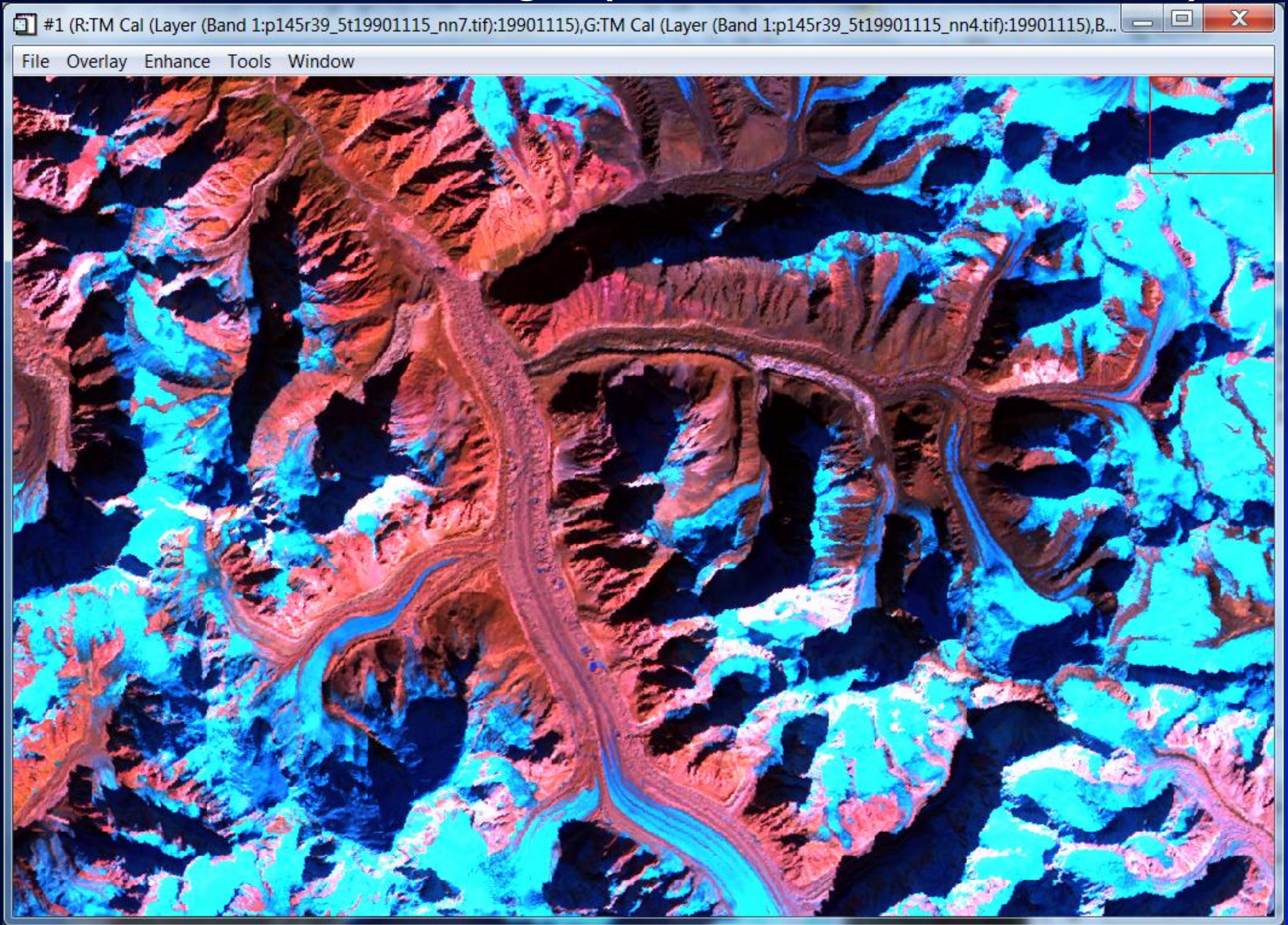
Data

(1) Landsat Thematic Mapper (TM) Images
- Acquired during 1990 – 2009
- 3 visible bands, 1 near-infrared (NIR) band, and 2 mid-infrared (MIR) bands.
- 30 m by 30 m spatial resolution

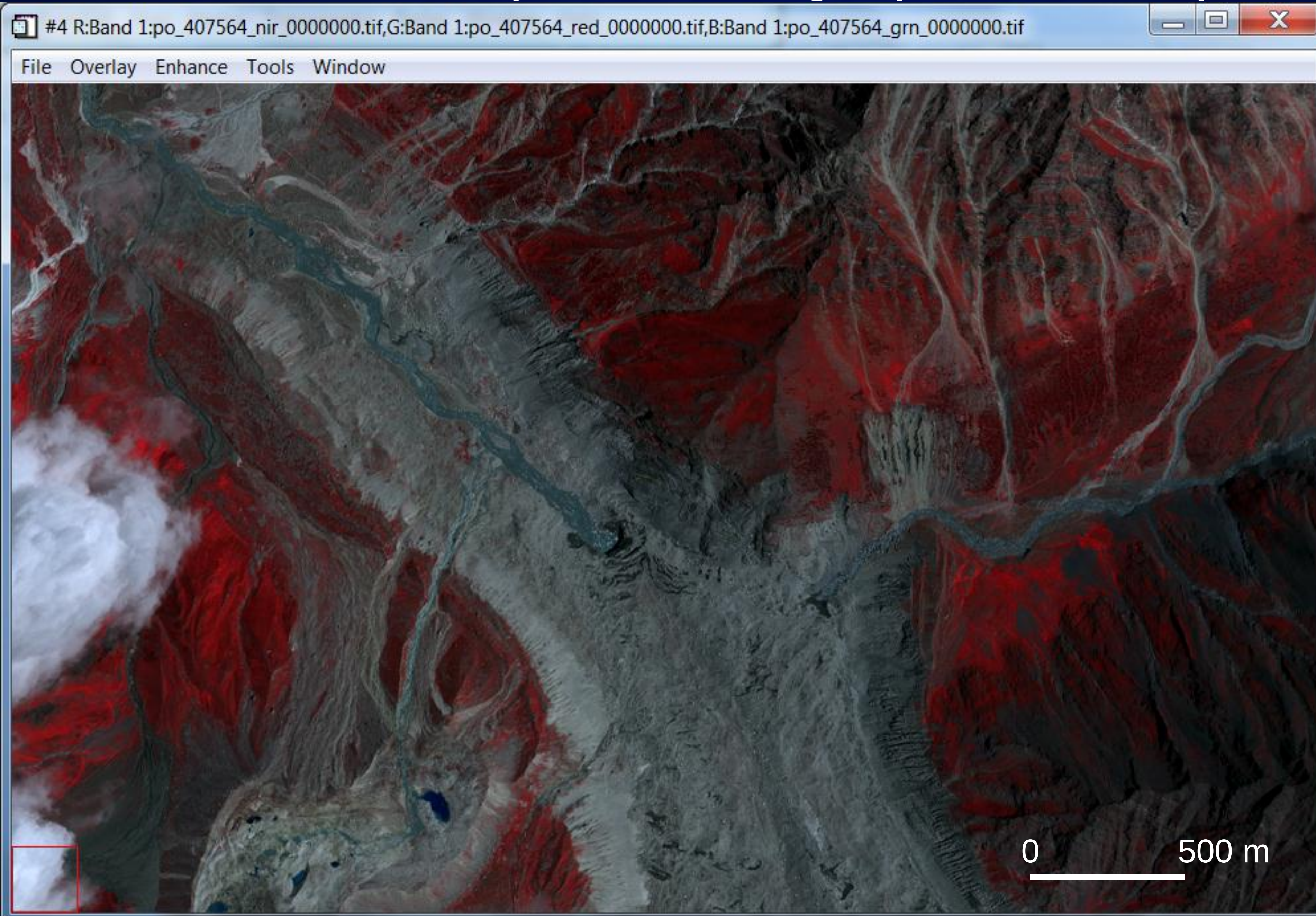
(2) IKONOS high resolution satellite images (2005)
- 4 m spatial resolution for multispectral bands
- 1 m spatial resolution for panchromatic band

(3) 90 m by 90 m Digital Elevation Model (DEM)
- Produced by the NASA Shuttle Radar Topographic Mission (SRTM) carried out by the Space Shuttle Endeavour in February 2000.

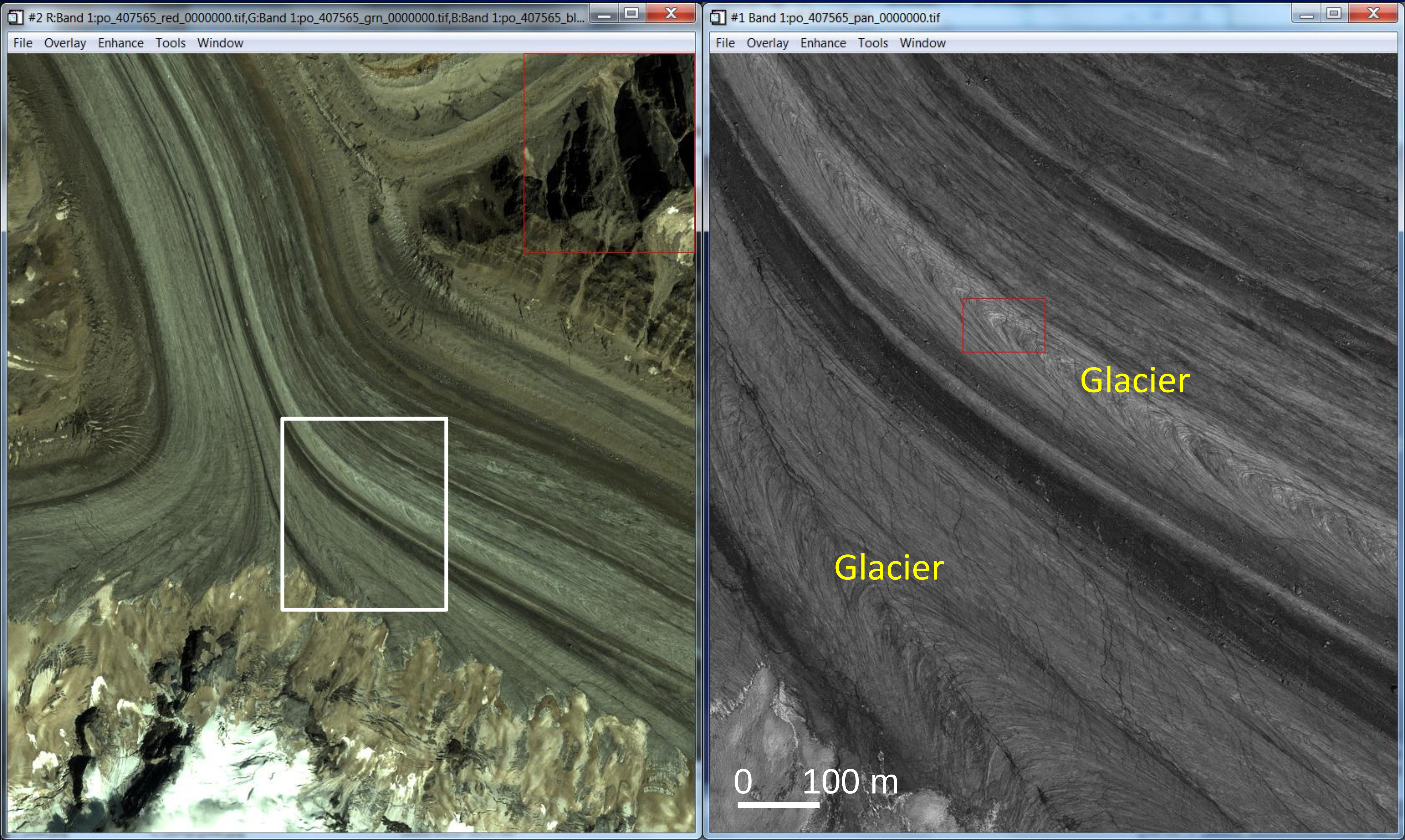
Landsat TM Image (1990/11/15, TM7, 4, 1)



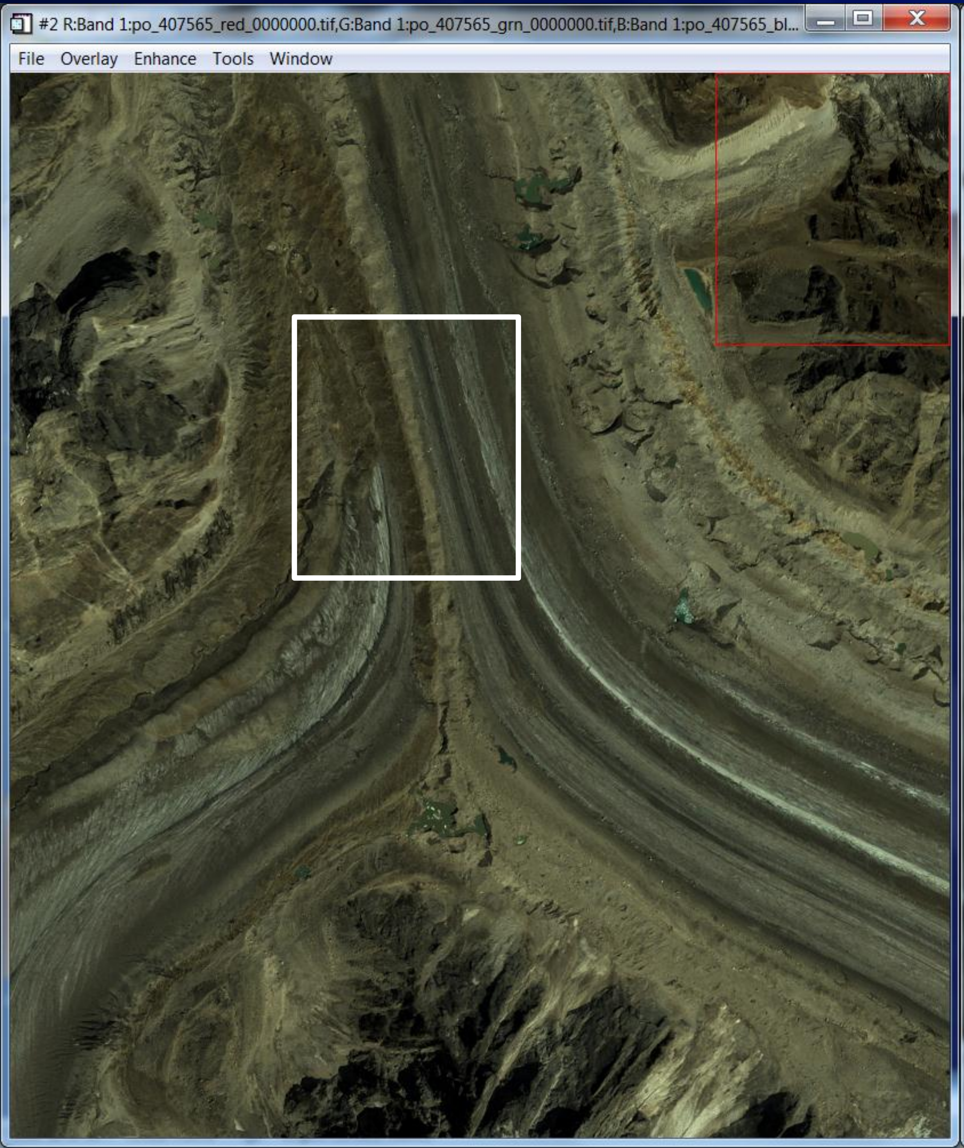
IKONOS Multispectral Image (2005/08/05)

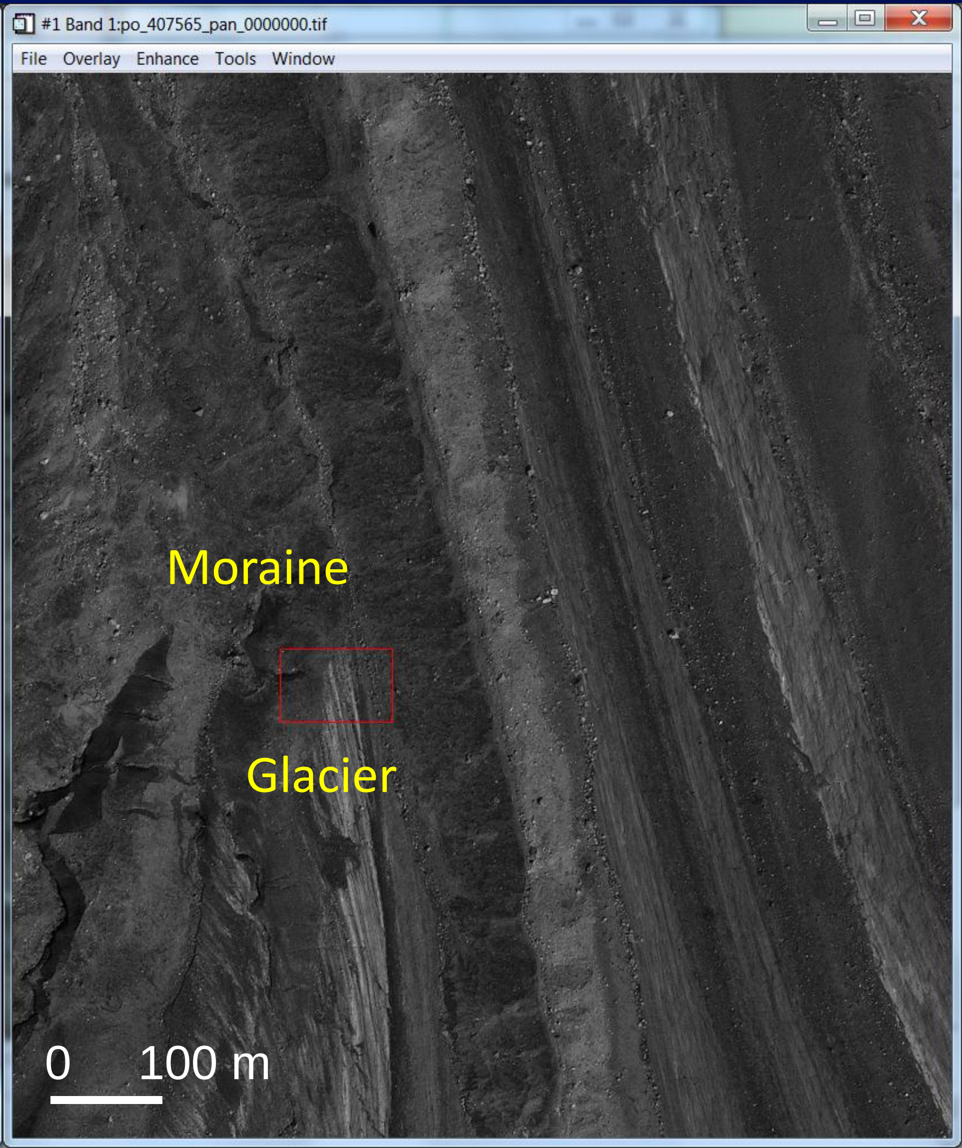


IKONOS Multispectral (left) and Panchromatic (right) Images (2005/08/05)

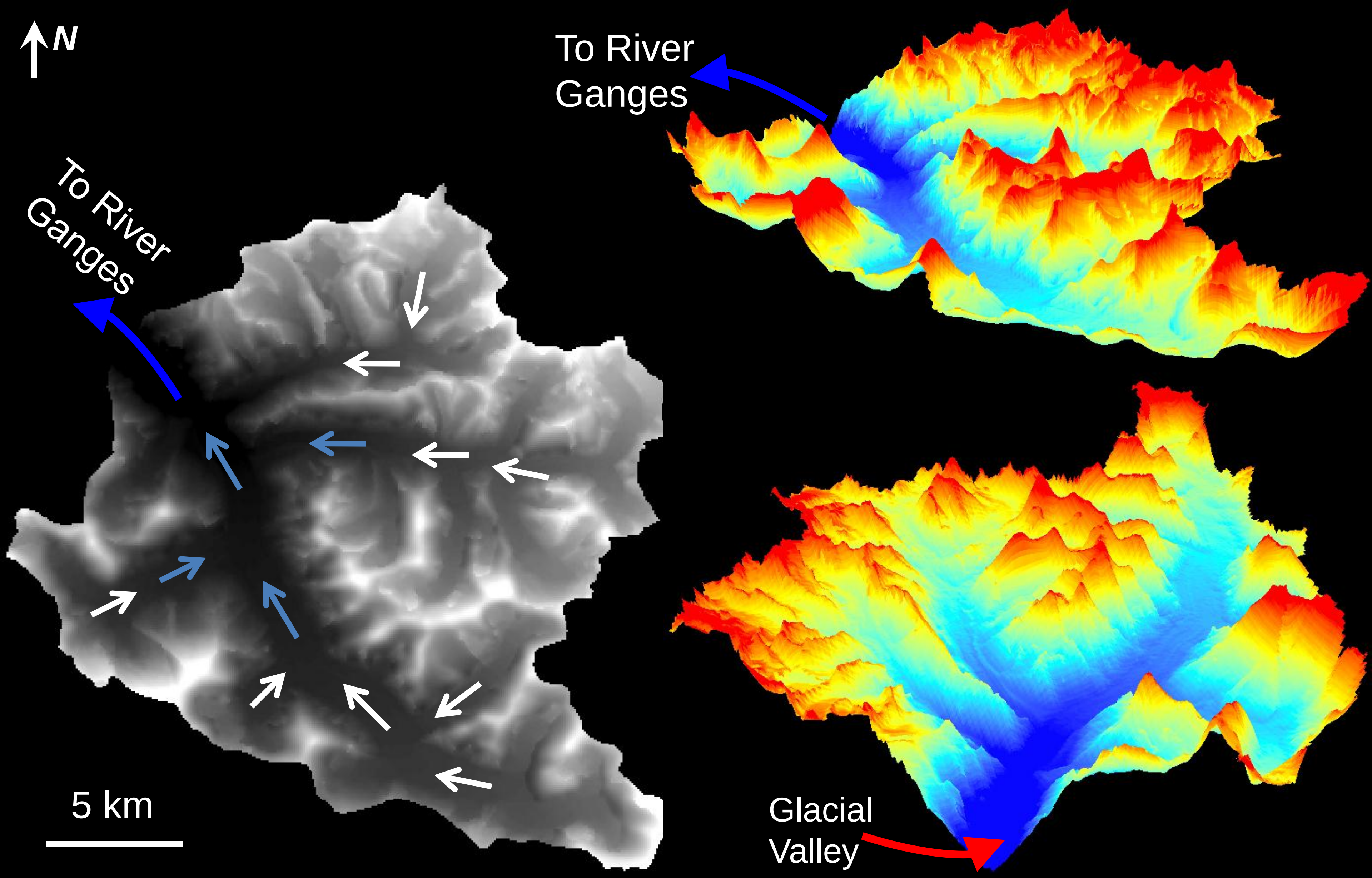


IKONOS Multispectral (left) and Panchromatic (right) Images (2005/08/05)





Digital Elevation Model (DEM) – Based on data from the NASA Shuttle Radar Topographic Mission (SRTM) in 2000



Methodology

- Pre-processing of Landsat TM images for more accurate image comparison;

- Extracting spectral properties of glacial and non-glacial features;

- Visual analysis of high resolution IKONOS images to identify glacial features;

- Change detection using multi-temporal Landsat TM images (1990 - 2009).

Methodology (1)

- Image pre-processing

(1) Converting digital numbers to radiance

$$L_\lambda = \frac{(L\max_\lambda - L\min_\lambda)}{Q_{cal\max}} Q_{cal} + L\min_\lambda$$

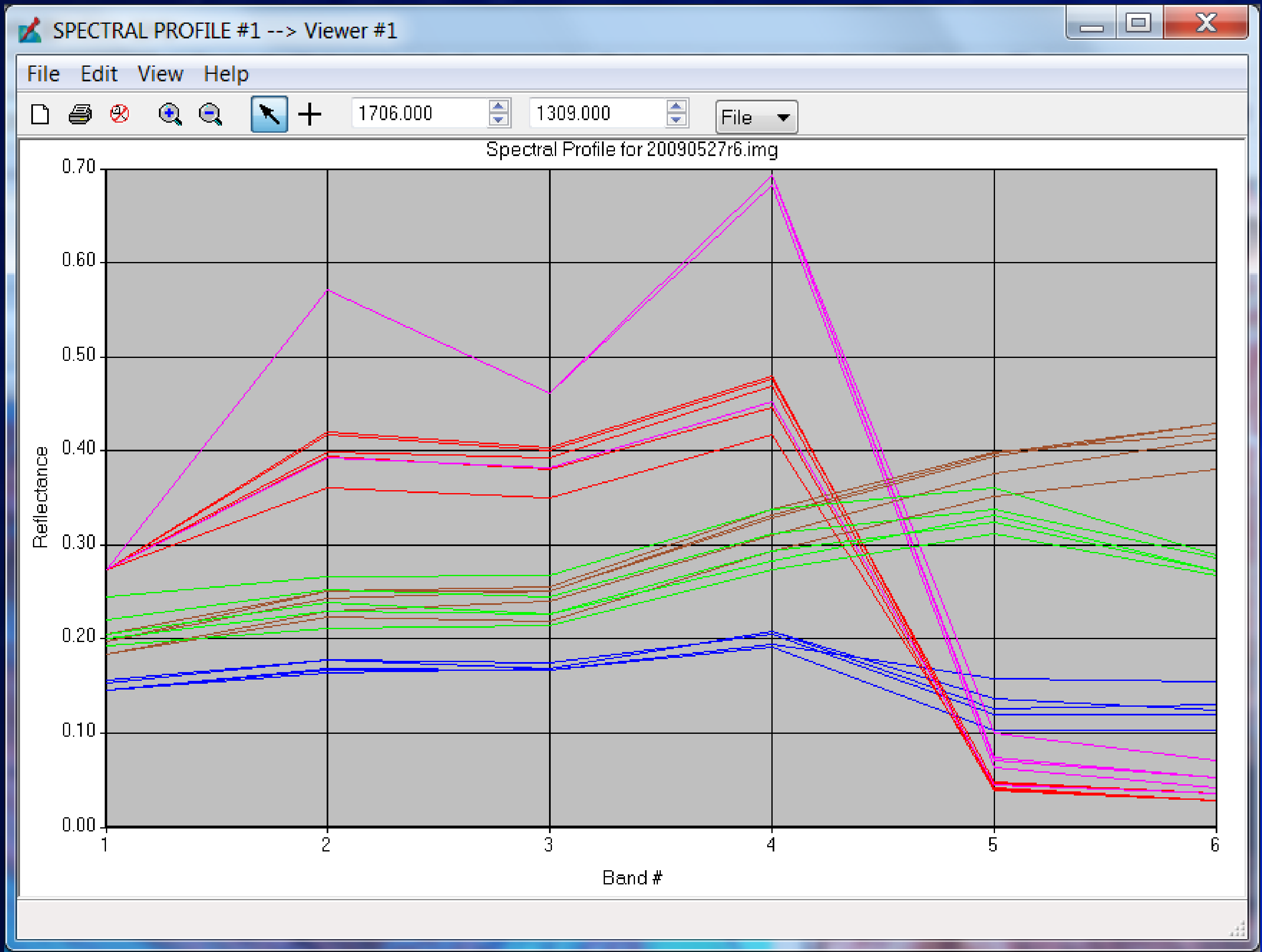
(2) Converting radiance to reflectance

$$\rho_p = \frac{(\pi * L_\lambda * d^2)}{ESUN_\lambda} \cos\theta_s$$

L_λ = spectral radiance at sensor's aperture in W/(m^2*sr*µm);
Q_{cal} = quantized calibrated pixel value in DNs;
Q_{calmax}= maximum quantized calibrated pixel value (DN = 255) corresponding to $Lmax_\lambda$;
$Lmax_\lambda$ = spectral radiance that is scaled to Q_{calmax} in W/(m^2*sr*µm);
$Lmin_\lambda$ = spectral radiance that is scaled to Q_{calmin} in W/(m^2*sr*µm);
ρp = unitless planetary reflectance;
d = earth-sun distance in astronomical units;
$ESUN_\lambda$ = mean solar exatmospheric units;
θ_s = solar zenith angle in degree.

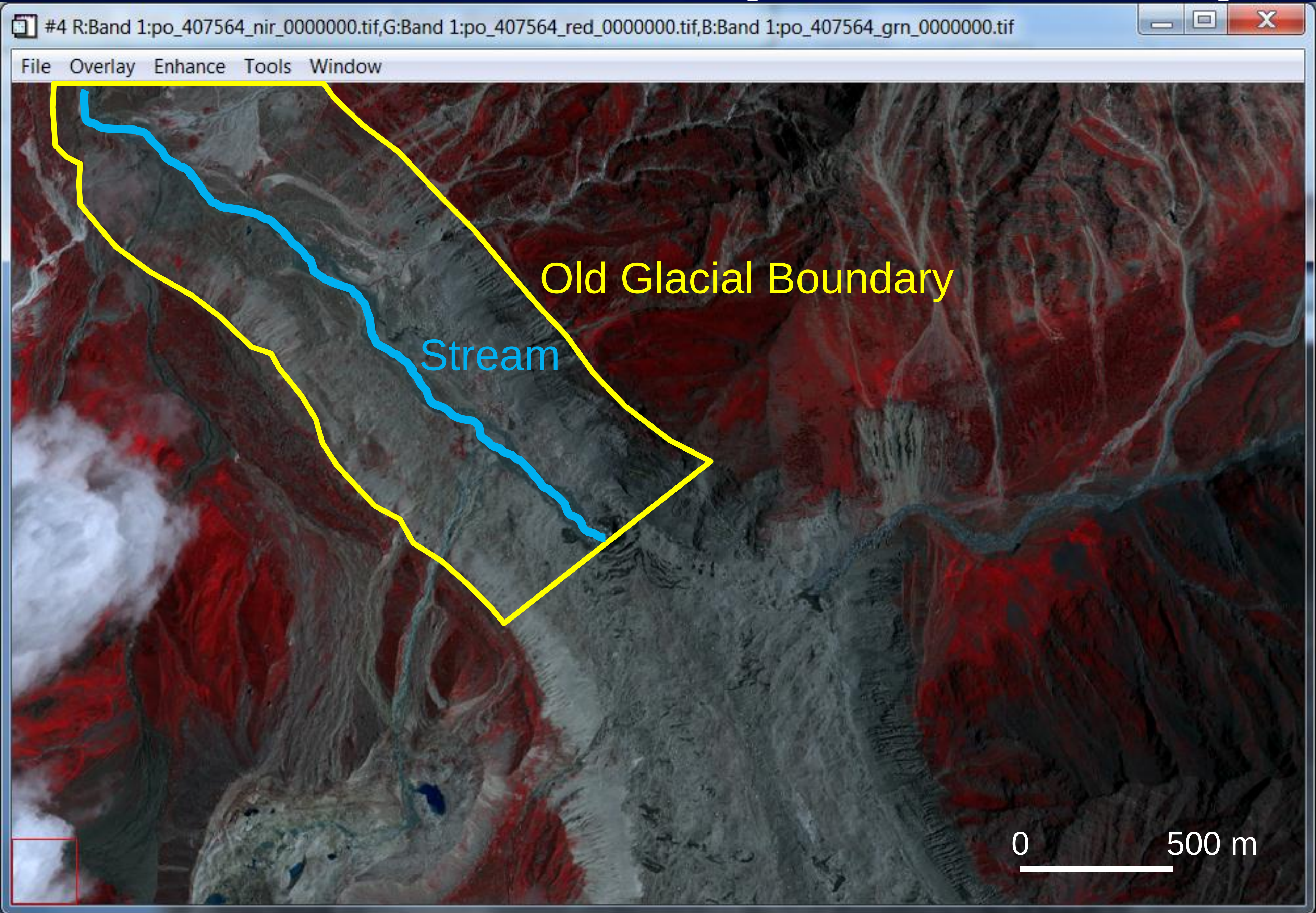
Methodology (2)

- Extracting glaciers using spectral properties

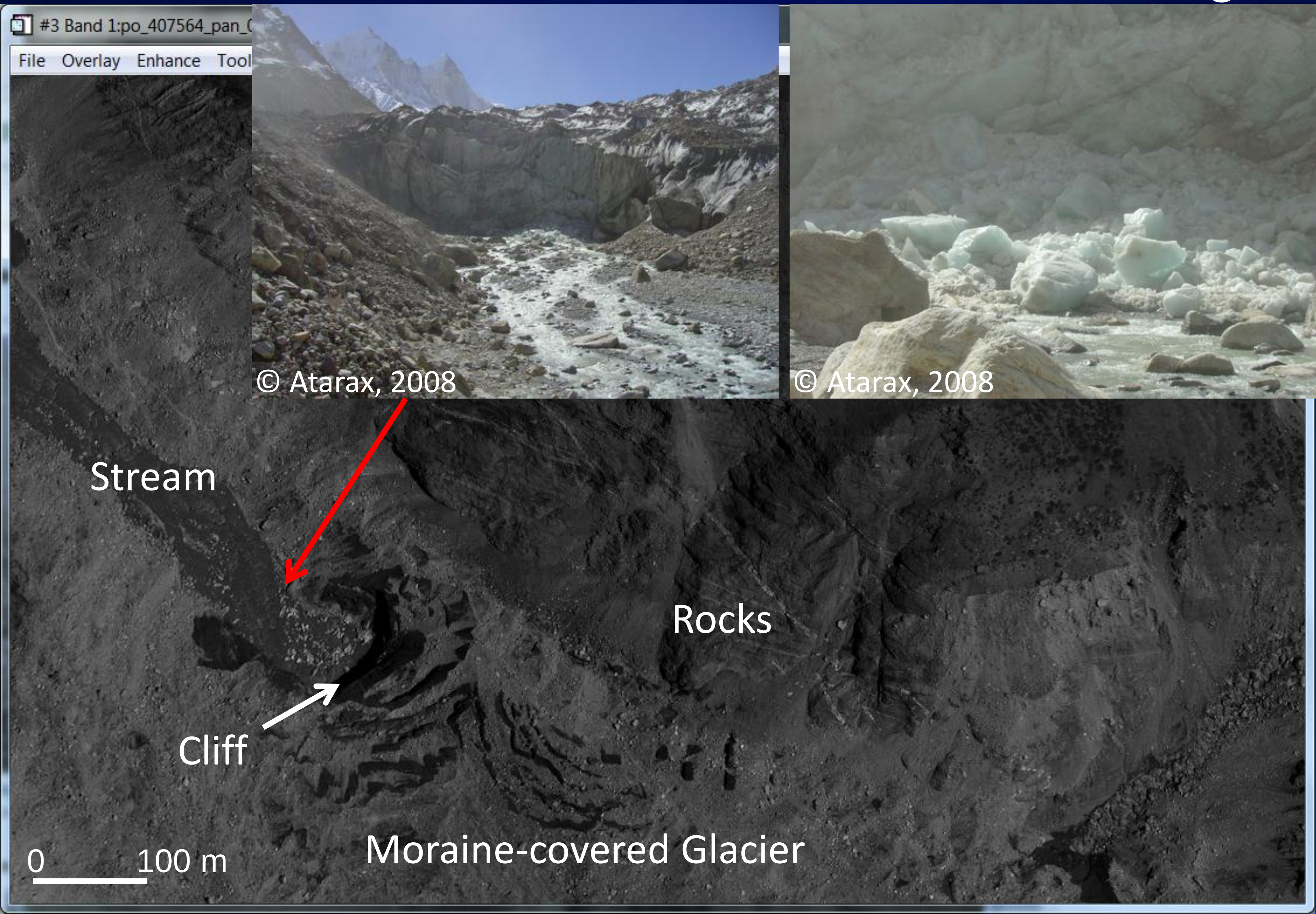


Results

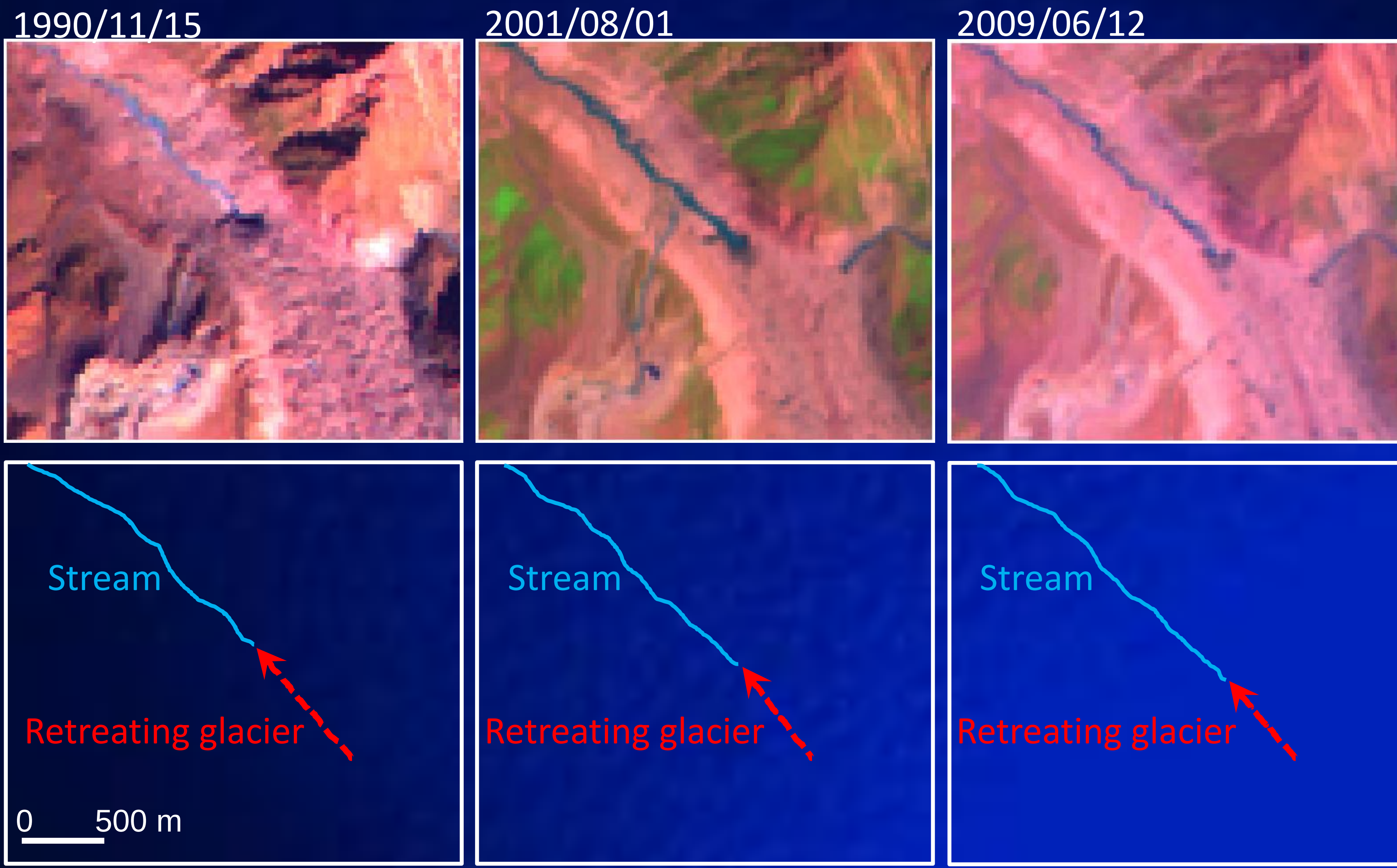
Traces of Glacier Retreating on IKONOS Image



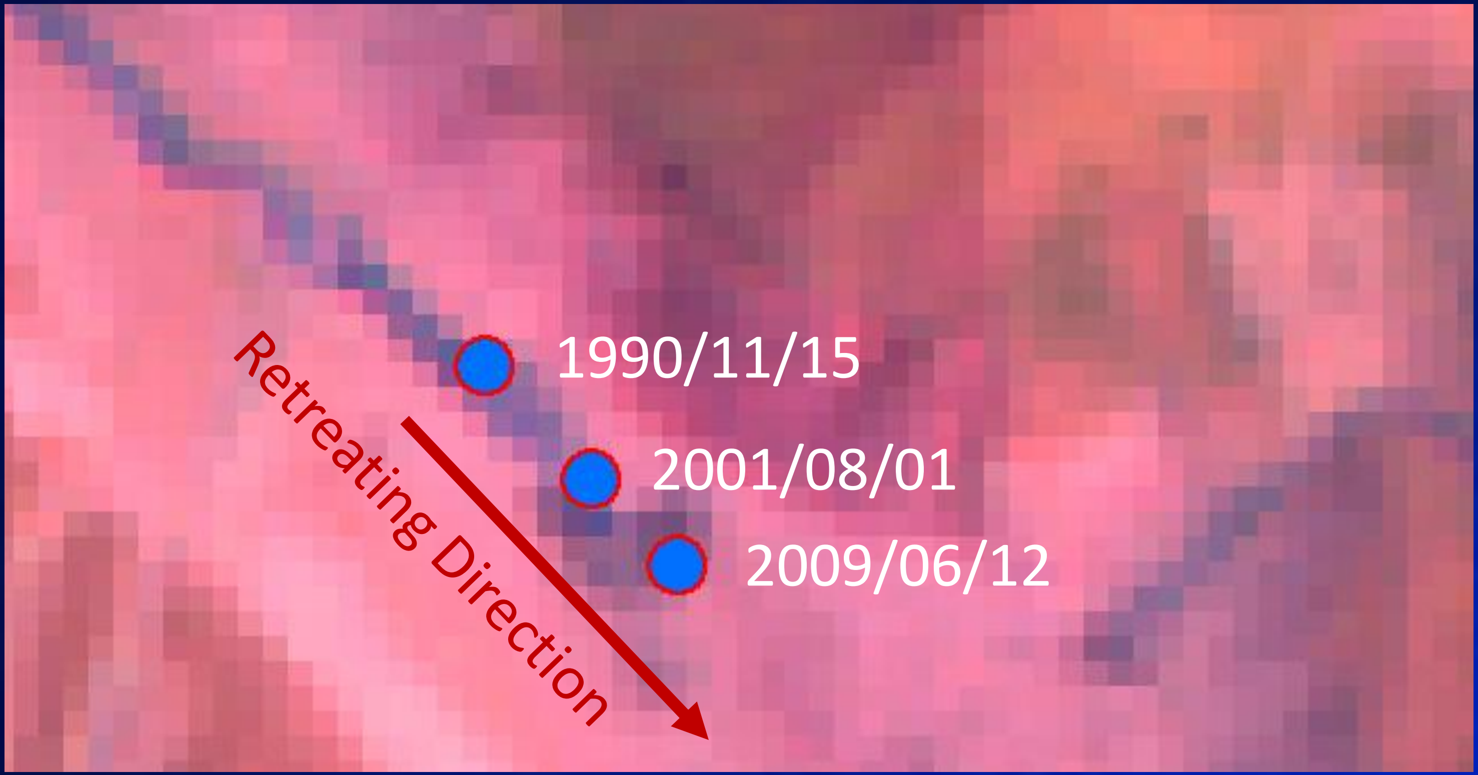
Features on 1-Meter Resolution IKONOS Image



Multi-temporal Comparison of Landsat TM Images



Retreating Rate of Moraine-covered Glacier



Time	Retreating Distance	Retreating Rate
1990 – 2001	202 m	18.36 m/year
2001 – 2009	143 m	17.88 m/year
1990 – 2009	345 m	18.16 m/year

Conclusions

(1) The medium resolution Landsat TM images provided important spatial, spectral, and temporal information on changes of the Gangotri Glacier from 1990 to 2009. High resolution IKONOS images and the medium resolution SRTM digital elevation model provided additional information on glacial geomorphology and flow direction.

(2) From 1990 to 2009, the moraine-covered Gangotri Glacier retreated 345 meters, with a retreating rate of approximately 18 meters per year. There are no obvious changes in retreating rate during 1990 – 2001 and 2001 – 2009.

(3) The River Ganges may potentially become a seasonal river as a result of continued glacier retreating, affecting hundreds of millions of people on the Indian subcontinent.

Acknowledgments

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Questions?